

# Common beliefs about the generators of the auditory evoked field challenged by high-resolution studies in single subjects

B. Lütkenhöner, C. Lammertmann, and O. Steinsträter

*Institute of Experimental Audiology, University of Münster, Münster, Germany*

## 1 Introduction

Animal experiments as well as invasive recordings in humans revealed a high complexity of the functional organization of the auditory cortex. Compared to that, the common interpretation of the auditory evoked field (AEF), based mainly on the peak structure of the recorded data, appears overly simple. Sufficient evidence of a more complex structure of the sources underlying the AEF is actually available. However, such details are generally sacrificed when trying to extract parameters common to all investigated subjects. While such a procedure has the advantage of resulting in handy conclusions, it entails the risk that interpretations do not sufficiently reflect the reality. Extensive investigations of single subjects can help to gain more insight into these problems.

## 2 Methods

Four subjects have been investigated in great detail. Tonebursts with a duration of 100 ms and carrier frequencies of 250 Hz, 1000 Hz, and 2000 Hz were presented to the right ear of the subject (interstimulus interval randomized between 800 and 1200 ms). Stimulus intensity was 60 dB sensation level (SL). The overall measurement time per subject was about 12 hours, subdivided into 14 sessions. About 14 000 epochs were recorded for each of the three stimulus frequencies.

The magnetic field was recorded over the contralateral (left) hemisphere using a 37-channel gradiometer system (Biomagnetic Technologies, Inc). Source parameters were derived by maximum likelihood estimation using the model of a current dipole in a sphere [1]. The coordinates from the different sessions were aligned as described in [2].

## 3 Results

The spatio-temporal pattern of the AEF reveals a considerable interindividual variability, but a high intraindividual consistency. Fig. 1 shows data from one

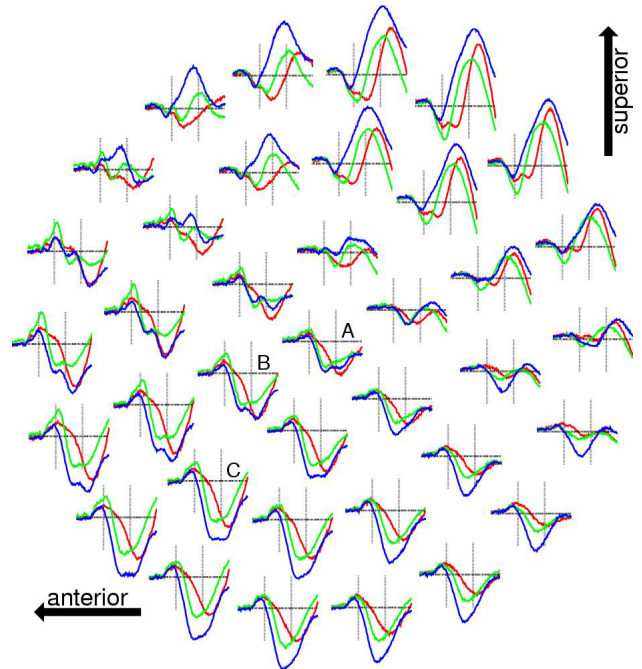


Figure 1: *Sensor-layout plot of responses to tonebursts of 100 ms duration (time window corresponding to the first 150 ms after stimulus onset). The three different stimulus frequencies are represented by the colors red (250 Hz), green (1000 Hz), and blue (4000 Hz). The curves represent grand averages of all 14 sessions available for subject g42.*

subject in a sensor-layout representation. The time window plotted corresponds to the first 150 ms after stimulus onset. The dotted vertical lines indicate the times 50 ms and 100 ms, respectively, which roughly correspond to the deflections P1m and N1m of the auditory evoked field (AEF). The three different stimulus frequencies (250 Hz, 1000 Hz, and 4000 Hz) are represented by the colors red, green, and blue, respectively. It is evident that the latencies of the major peaks exhibit a considerable frequency dependence. However, it seems difficult to characterize this dependence in simple terms as the response pattern varies from channel to channel. In some channels even two peaks can be observed in the N1m latency range. Three such channel (indicated by the letters A,

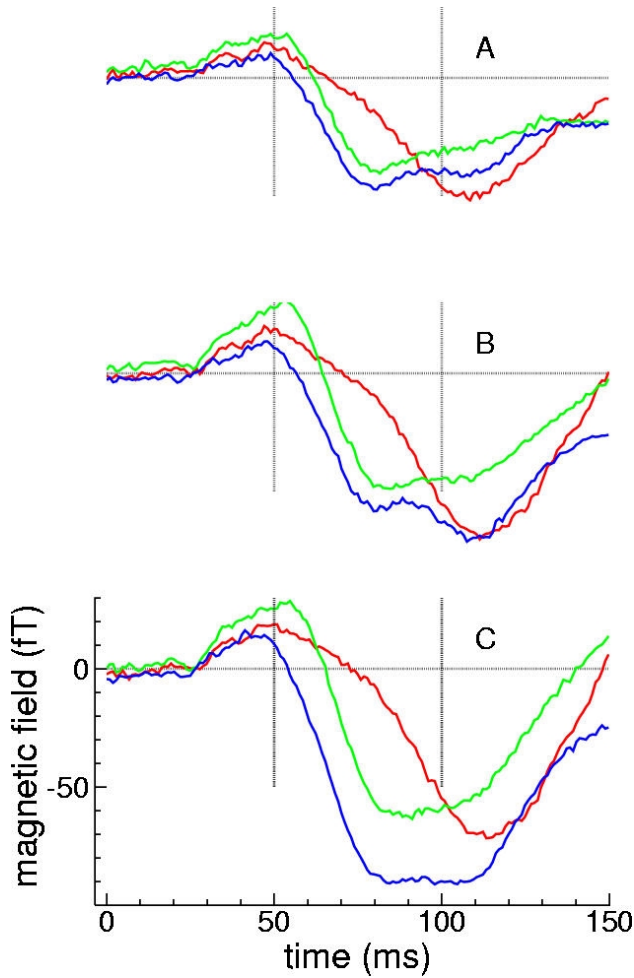


Figure 2: Three selected channels of Fig. 1 in a larger scale.

B, and C) are presented in Fig. 2 in a larger scale. In channel A, the responses to the 1000 Hz tone (green) and the 4000 Hz tone (blue) show a pronounced negative peak at about 75 ms. The 4000 Hz response shows a smaller *second* peak at about 110 ms, which almost coincides with the N1m peak in response to the 250 Hz tone (red curve). A similar pattern can be observed in channel B, except that the amplitude ratio of the two negative peaks in response to the 4000 Hz tone is reversed. In channel C, these two peaks apparently fused to a single broad peak. Owing to the huge number of epochs available for averaging, it can be excluded that these subtle pattern changes reflect superposed noise.

Fig. 3 shows an overlay of the AEF waveforms of all 37 channels (upper panel: 250 Hz; middle: 1000 Hz; bottom: 4000 Hz). It is evident that not only the shape of deflection N1m, but also that of deflection P1m is highly dependent on the stimulus frequency. Stimuli

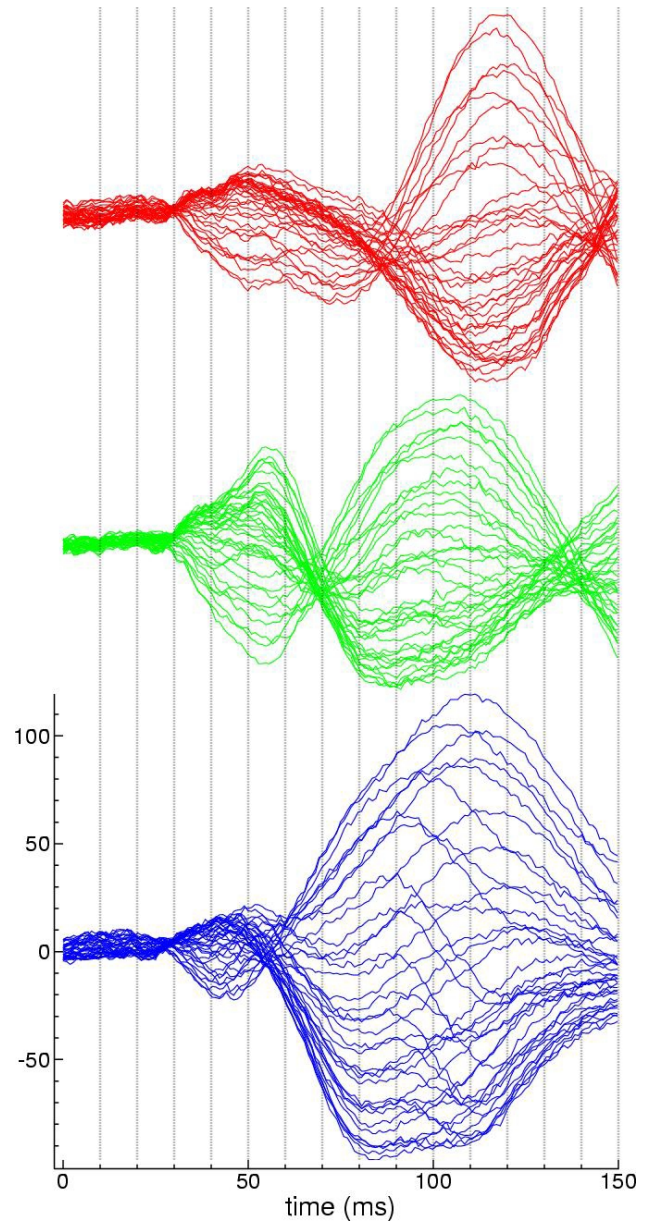


Figure 3: Same data as in figures 1 and 2, but overlay of all 37 channels.

of 1000 and 4000 Hz elicited a single P1m deflection (with an apparent middle latency wave riding on it at 1000 Hz), whereas two deflections were elicited by the 250 Hz stimulus (the second one having a latency of about 70 ms).

A compact representation of the most basic aspects of the spatio-temporal response pattern is obtained by plotting the coordinates of the estimated equivalent current dipole as a function of time. Figures 4 and 5 show in the upper panel the root mean square (RMS) value of the 37 channels as a function of time, and in the bottom three panels the time dependence of the

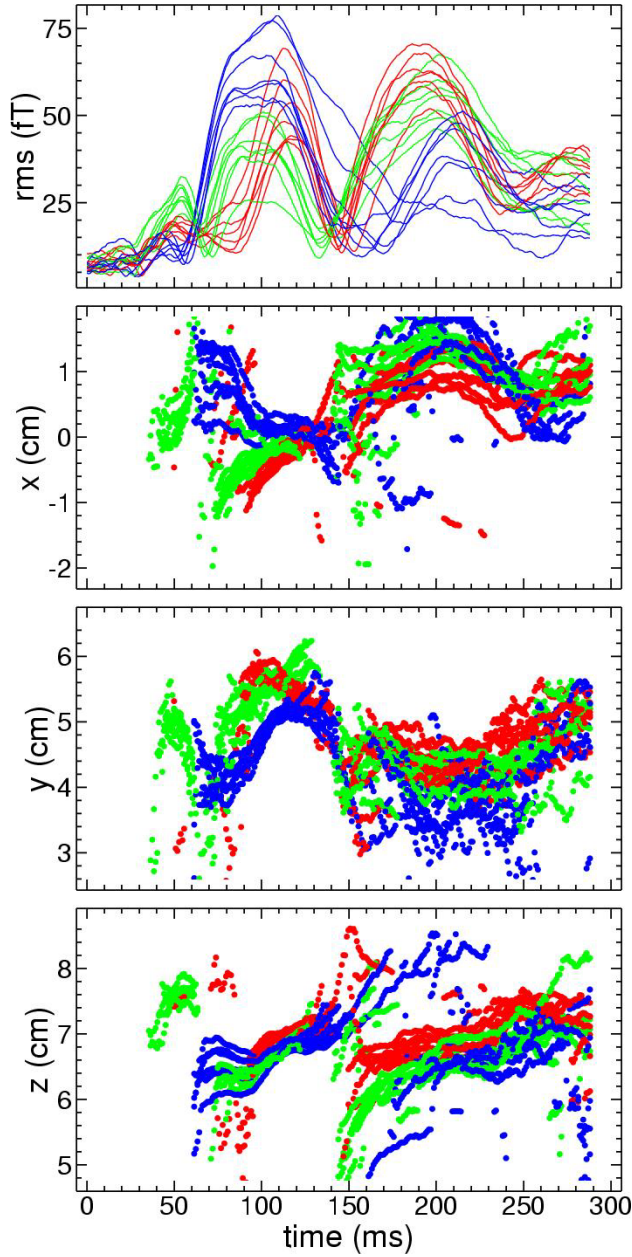


Figure 4: Result of “moving dipole” source analyses of subject g42 (overlay of results from 7 days). Upper panel: Root-Mean-Square (RMS) curves. Other panels: estimated coordinates. The three coordinate axes roughly point from posterior to anterior ( $x$ ), from medial to lateral ( $y$ ), and from inferior to superior ( $z$ ). Same color coding as in Fig. 1.

three Cartesian coordinates. Looking at these plots, a convincing component structure is even more difficult to find than it was on the basis of the figures 1–3. A consistent feature in both figures is a discontinuity of the estimated dipole coordinates at about 130 ms, corresponding to the transition between deflections N1m

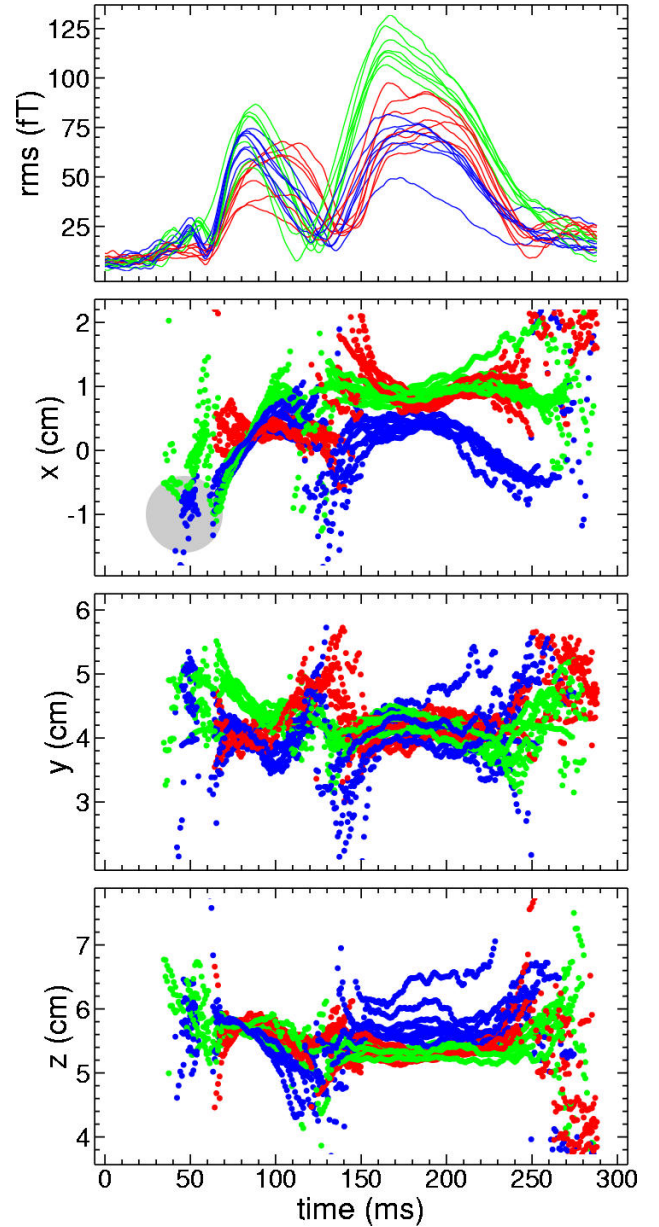


Figure 5: As Fig. 4, but for subject A08. The highlighted area (grey) indicates a P1m source located posterior to the N1m sources.

and P2m. Thus, different sources are responsible for these two deflections. However, the definition of a single dipole location for each deflection would be quite arbitrary, because the estimated location actually moves on a three-dimensional trajectory. In some time windows, a tonotopic arrangement of the estimated dipole locations can be observed. This “tonotopy” is most pronounced in subject g42 in the N1m latency range. The results obtained for the  $y$ -coordinate are consistent with reports in previous studies (“the higher the frequency, the deeper the

source”). On the other hand, a quite different pattern for this latency range was obtained in subject A08.

Some of the source localization results turned out to be puzzling, casting shadows of doubts on seemingly established facts. For example, the 4000 Hz results in Fig. 4 (blue) suggest the existence of an early N1m component located about 1 cm anterior to both the P1m source and the later N1m source (the latter two differing in the other two coordinates, though). In subject A08 (Fig. 5) a highly reproducible source in the P1m latency range was observed about 1 cm posterior to the sources responsible for the later parts of N1m (indicated by the grey spot).

Fig. 6 shows that filtering may have a significant impact on the source locations. The filled circles correspond to deflection N1m of the 100 Hz low-pass filtered data, whereas the symbols ‘x’ were obtained for a pronounced deflection in the 20-100 Hz band-pass filtered data, which had a latency of 70 ms (basically representing the rising slope of N1m). After filtering, the dipoles estimated for 250 Hz were located about 5 mm more anterior.

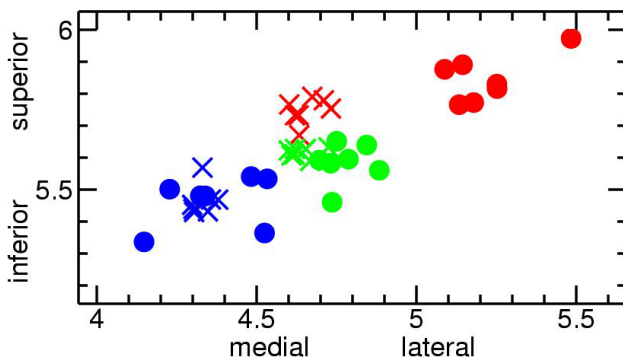


Figure 6: Influence of filtering on the estimated dipole locations. Filled circles based on 100 Hz low-pass filtered data, symbols ‘x’ based on 20-100 Hz band-pass filtered data.

## 4 Discussion and Conclusions

AEF measurements provide a considerable amount of spatial information. One possibility to extract such information is a “moving dipole” source analysis. The source representations derived in this way are highly reproducible so that they can be considered as some kind of cortical “fingerprint”. The high intraindividual reproducibility of the response pattern contrasts with a considerable interindividual variability, which presumably reflects the anatomical variability of the

underlying cortical structures.

While a proper interpretation of the complex response patterns revealed in this study is difficult, it is easy to disprove the assumption (implicitly made in most AEF studies) that each peak arises from one distinct generator. Thus, care is required when interpreting a small change in dipole location, direction or amplitude in dependence of some experimental parameter, because several alternative hypotheses are conceivable. Moreover, the considerable dependence of the spatio-temporal response pattern on the stimulus frequency gives rise to the question as to how useful the common subdivision of the response pattern into peaks really is.

## Acknowledgements

Supported by the Deutsche Forschungsgemeinschaft under Grant Lu342/4-2.

## References

- [1] B. Lütkenhöner. Dipole source localization by means of maximum likelihood estimation: I. Theory and simulations. *Electroenceph. clin. Neurophysiol.*, 106:314–321, 1998.
- [2] B. Lütkenhöner and O. Steinsträter. High-precision neuromagnetic study of the functional organization of the human auditory cortex. *Audiol. Neuro-Otol.*, 3:191–213, 1998.